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**SMALL, NON-NATIVE MAMMAL INVENTORY IN
KALAUPAPA NATIONAL HISTORICAL PARK**

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ABSTRACT

A presence/absence survey for small non-native mammals was conducted in Kalaupapa National Historical Park March–May 2005. The survey consisted of seven 500-m transects, each with 11 stations, except for one transect which had nine stations (75 stations total). One large and two small snap traps, a Tomahawk® live trap, a tracking tunnel, and a glue board were set at each station. Small mammal trapping was conducted for three nights in the spring of 2005 along each transect for a total of 215.5 corrected trap nights for cats and mongooses, 430 for rats, and 830 for mice. Results indicate the presence of black rats (*Rattus rattus*), house mice (*Mus musculus*), mongooses (*Herpestes javanicus*), and feral cats (*Felis catus*) in the park. Trapping indicated average capture rates per 100 trap nights of 3.48 for black rat and 1.2 for mouse. Forty-two mongooses and two feral cats were captured. No evidence of Polynesian rats (*Rattus exulans*) or Norway rats (*Rattus norvegicus*) was detected in our sample. For mice and rats, the number of tracking tunnel signs was low even on transects where the capture rate by snap or glue traps was high. However, for mongooses and cats the number of tracking tunnel signs was proportionally higher than the overall capture rate.

INTRODUCTION

Introduced mammalian predators threaten native Hawaiian flora and fauna in various ways. Though endemic Hawaiian birds evolved with native avian predators such as hawks and owls, there was an absence of native mammalian predators. Because mammals and raptors hunt birds in different ways, selective pressures from raptors are likely different than from mammals, thus making birds susceptible to mammalian depredation (Moors et al. 1992, Stone et al. 1984). Non-native mammals consume a variety of native bird, invertebrate, and plant foods (Kami 1966, Scowcroft and Sakai 1983, Male and Loeffler 1997, Sugihara 1997, Wanless et al. 2007), thus potentially reducing the availability of food for forest birds and contributing to habitat degradation. Predation on native plant fruits and seeds also represents a threat to rare plant populations (Chimera 2004) and selective pressures on particular species can potentially create long-term shifts in the composition and structure of plant communities (Allen et al. 1994).

Three species of rats have arrived in the Hawaiian Islands since colonization by humans. Polynesian rats (*Rattus exulans*) were brought by the early Polynesian settlers around 400 AD (Kirch 1982). Norway rats (*R. norvegicus*) were established on the islands shortly after Captain James Cook arrived in 1778, and black rats (*R. rattus*) reached Hawai'i in the late 1800s (Tomich 1986). Both Polynesian and black rats are well adapted to the ecological conditions in forests in Hawai'i (Sugihara 1997). All three rat species contribute to the decline of native forest bird species in Hawai'i, though the black rat is considered the most significant avian predator of the three species due to its arboreal life style (Atkinson 1977, Ebenhard 1988). The extirpation of the Laysan Rail (*Porzana palmeri*) and Laysan Finch (*Telespiza cantans*) from Midway Island in the 1940s was attributed to an extreme rat infestation (Fisher and Baldwin 1946). In addition to being a threat to native bird species, black rats are known to prey on native snails (Hughes unpubl. data), the fruits of sandalwood (*Santalum* spp.), and other vulnerable Hawaiian plant species (Loope et al. 1988). Norway rats are occasionally found in low and mid-elevation forest, residing close to urban and agricultural areas where food is more secure (Tomich 1986, Tobin and Sugihara 1992, Lindsey et al. in press). Thus, Norway rats pose the smallest threat of the three species of rats to native fauna because they do not invade very far into native forests (Tomich 1986, Lindsey et al. in press).

The house mouse (*Mus musculus*) is the most ubiquitous non-native mammal in Hawai'i. House mice can compete with native Hawaiian fauna for food resources as well as provide a food base for more threatening non-native carnivores. Although the house mouse is not typically viewed as a direct predator of native fauna, house mice have recently been documented preying on albatross chicks on the South Atlantic island of Gough (Wanless et al. 2007).

The small Indian mongoose (*Herpestes javanicus*) was released in Hawai'i in 1883 as an unsuccessful biological control agent of rats (Tomich 1986). Mongooses are the largest threat to ground nesting seabirds and contribute to the reduction of Newell's Shearwater (*Puffinus auricularis newelli*) on Moloka'i (Harrison 1990, Ainley et al. 1997). Mongooses have also been a factor in the decline of the endangered Nēnē (*Branta sandvicensis*), as the eggs and brooding females are particularly defenseless on the ground (Banko 1992, Banko et al. 1999). Laboratory tests show that mongooses are good tree climbers (Stone and Loope 1987) and may also depredate native forest bird species.

Domestic cats (*Felis catus*) arrived in the Hawaiian Islands with European explorers and settlers, and feral populations became established by the early 1800s (Tomich 1986). Feral cats are present on all the main Hawaiian Islands. They range from sea level, where populations are higher as a result of abandoned pets and feeding by humans, to isolated montane forests and alpine areas of Maui and Hawai'i (Simons 1983, Hu et al. 2001, Winter 2003, Hess et al. 2004). Feral cats are a major predator of native forest and ground-nesting birds. The endangered Hawaiian Goose or Nene and the endangered Hawaiian Petrel (*Pterodroma phaeopygia sandwichensis*), both ground-nesting species, have suffered depredation by feral cats (Simons 1983, Banko 1988, Natividad Hodges 1994, Baker and Baker 1996, Natividad Hodges and Nagata 2001). Feral cats also depredate roosting forest birds, and have been observed taking nestlings from nests (Hess et al. 2004).

Before this inventory small mammal trapping had not occurred in Kalaupapa National Historical Park (KALA). This inventory was conducted to document the presence or absence of these six mammalian species in the park. Our survey provides baseline data for future studies and information for management decisions regarding these species. This inventory also helps to fulfill the goal of the National Park Service Inventory and Monitoring program to document 90% of vertebrates and vascular plants in national parks.

There is a high level of interest in controlling introduced rodent and small mammal populations in managed areas in Hawai'i to reduce predation on native plants and animals. In order to achieve meaningful results and be cost effective, recent programs focus on the use of rodenticides; however, there are concerns for environmental health and for non-target species in the implementation of these programs.

One recent project undertaken by the State of Hawaii Department of Land and Natural Resources and the United States Fish and Wildlife Service set out to eradicate rats from Mōkapu Islet just outside the KALA boundary. The removal of rats serves to protect the rare native plant species hō'awa (*Pittosporum halophilum*) and loulou palm (*Pritchardia hillebrandii*) and several ground-nesting seabirds including Wedge-tailed Shearwaters ('ua'u kani, *Puffinus pacificus*), Red-tailed Tropicbirds (koa'e 'ula, *Phaethon rubricauda*), and White-tailed Tropicbirds (koa'e kea, *Phaethon lepturus*) (Wilson 2008). These same species occur on the adjacent islands of Huelo and 'Ōkala, but no rodents have been found there to date. Rodenticide poisons readily break down in sunlight and bind to inert substances making them unavailable to the biotic food chain. As a precaution, efforts were made to control the application of the aerial-broadcast rodenticide so it would be restricted to the island. Project managers of the Mōkapu Islet eradication program sampled several marine organisms before and after the application of rodenticide and found no poison in the non-target species sampled (Swenson 2008). Other studies examined the effects of rodenticides on non-target species and their pathways in food webs. The findings predicted low probabilities that non-target rare native forest birds and native snails would be affected by these poisons (Johnston et al. 2005). There is potential for properly selected and conducted rodent poison control programs in Hawai'i.

Habitat Description

Located on the island of Molokaʻi, KALA is 5,261 hectares in size and encompasses Kalawao County (Figures 1 and 2). The county includes the Kalaupapa Peninsula and settlement of the same name, a volcanic crater, adjacent cliffs and valleys, and submerged lands and water out to 400 m from shore. Kalaupapa Peninsula was formed 400,000 years ago from lava flows of a tiny rejuvenated-stage shield volcano that developed immediately off the north shore of the island (Juvik and Juvik 1998, Ziegler 2002). The volcano shield is about three kilometers across and rises to 122 m above sea level. The islets, which lie almost one kilometer from shore, are isolated by marine erosion (MacDonald et al. 1983). Though within the park's boundary, the islets are owned and managed by the state as bird sanctuaries. The island's north shore sea cliffs that rise up to one kilometer (Ziegler 2002) are the result of a great landslide 1.5 million years ago. The landslide slid northward and propelled kilometer-sized blocks into the ocean as far as 161 km offshore (Juvik and Juvik 1998).



Figure 1. Aerial photo of Kalaupapa Peninsula looking eastward, Kalaupapa National Historical Park, 2005.

The terrestrial landscape of the park consists of wet and mesic forest, dryland forest and shrub, and coastal strand communities. The wet and mesic forests range from intact native forests dominated by ʻōhiʻa (*Metrosideros polymorpha*) and tree ferns at high elevation (730–1180 m), to non-native dominated Java plum (*Syzygium cumini*) and strawberry guava (*Psidium cattleianum*) forest in the lowlands (20–200 m). Java plum and guava forests on valley bottoms typically have an open understory, which is the result of high densities of feral goats, pigs, and deer, while Christmas berry (*Schinus terebinthifolius*) and lantana (*Lantana camara*) form dense thickets on the peninsula following the release of grazing pressure from the removal of horses and cattle in the 1980s (Scowcroft and Hobdy 1987, National Park Service 2000, 2004). The ground cover within high elevation native forests consists of uluhe (*Dicranopteris linearis*) ferns, shrubby alani (*Melicope* spp.), haʻiwale (*Cyrtandra* spp.), and kanawao (*Broussaisia arguta*), and grasses such as naturalized *Ehrharta stipoides* with some scattered non-native vegetation. The densely vegetated remnant dryland forest in Kauhakō Crater,

found in the center of the peninsula, is represented by native wiliwili (*Erythrina sandwicensis*) tree stands with a variety of native shrubs and trees, but is dominated by non-native plants.

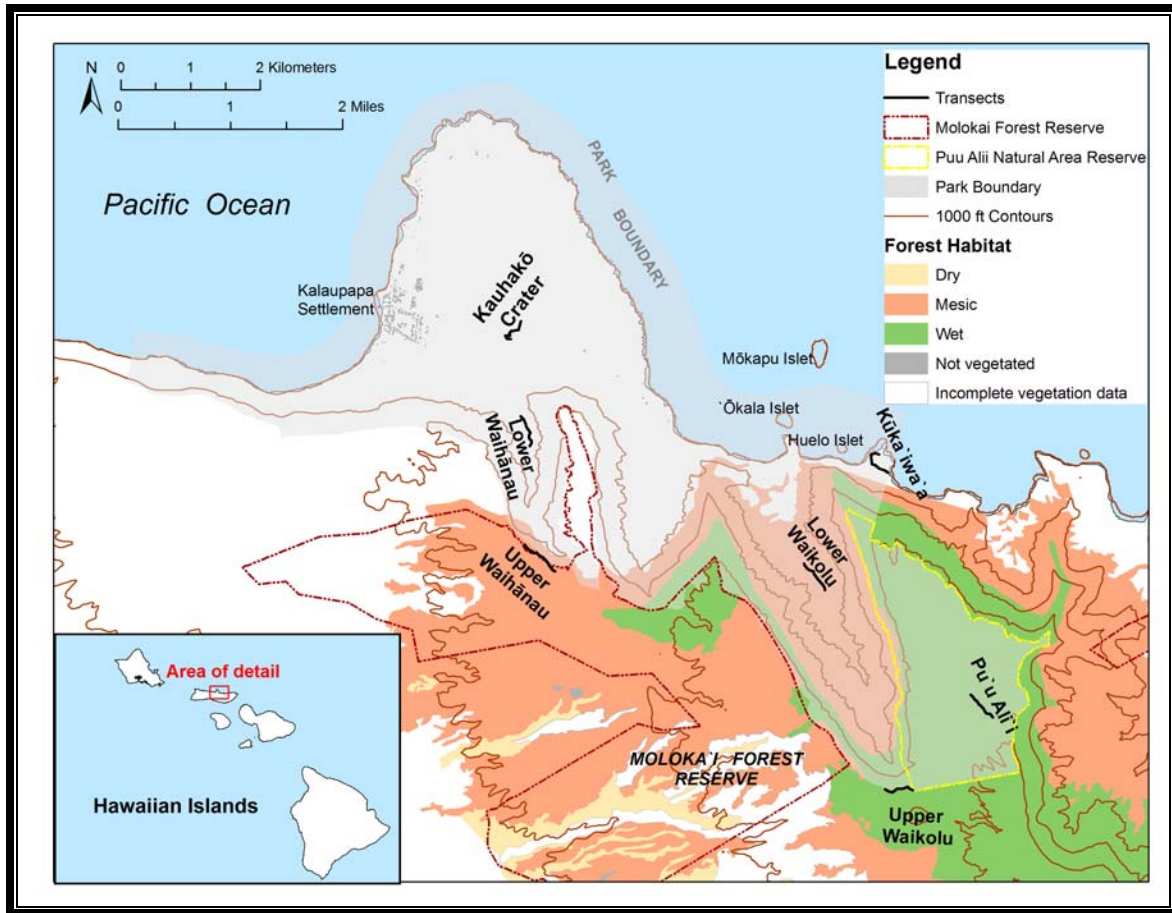


Figure 2. Map of non-native mammal survey transects at Kalaupapa National Historical Park, March–May 2005.

METHODS

Species distribution data from this inventory will be entered into NPSpecies (<https://science1.nature.nps.gov/npspecies/web/main/start>), the National Park Service Biodiversity Database. Currently, only National Park Service employees or contractors can access NPSpecies, but a website with accessibility for the public is being developed.

Transect Establishment

This inventory was conducted along seven 500-m transects consisting of a combination of newly established and pre-existing transects (Figure 2 and Table 1). Each transect consisted of 11 stations, except for the Kūka'iwa'a transect which had nine stations (75 stations total). The transects surveyed all coincide with the longer transects surveyed for the 2005 Forest Bird Inventory (Marshall and Kozar 2008). Waihānau Valley is the westernmost valley on Moloka'i's northern shore. The lower Waihānau transect (180 m elevation) runs north-south along the narrow floor of the valley, proximal to the intermittent stream. The upper Waihānau transect occurs at about 750 m elevation and

follows Pu`u Kauwā Road in the Moloka`i Forest Reserve. The transect overlooks Waihānau Valley and Kalaupapa Peninsula (Figure 3). Kauhakō Crater is the highest natural point on the peninsula at 122 m (Figure 4). The transect runs along the crater rim, descends, and follows along the plateau above the lake.

Table 1. Transect descriptions of the small mammal inventory, Kalaupapa National Historical Park, March–May 2005.

Transect	Elevation* (m)	Vegetation
Pu`u Ali`i NAR	1150–1180	Native: `ōhi`a, treefern, shrub
Upper Waikolu	1100–1140	Native: `ōhi`a, treefern, shrub
Upper Waihānau	730–780	Mixed: `ōhi`a as well as non-native trees
Lower Waihānau	160–200	Non-native: Java plum, guava spp.
Lower Waikolu	140–160	Non-native: guava spp., kukui (<i>Aleurites moluccana</i>)
Kauhakō Crater	30–100	Mixed: Christmas berry, lantana, wiliwili
Kūka`iwa`a	20–40	Mixed: hala (<i>Pandanus tectorius</i>), Java plum

*describes the elevation range covered by the transect—not necessarily beginning and end elevations of the transect; elevation ranges were determined using 20-m contour lines.



Figure 3. Photo of Kauhakō Crater and Kalaupapa Peninsula from upper Waihānau, Kalaupapa National Historical Park, 2005.



Figure 4. Aerial photo of Kauhakō Crater and Waihānau Valley, Kalaupapa National Historical Park, 2005.

Waikolu Valley lies east of Waihānau (Figure 5), and has been a water source for Molokaʻi since the early 1900s. The lower Waikolu transect (150 m elevation) runs north-south, along an old aqueduct pipe. A Hawaiʻi Forest Bird Survey (HFBS) transect covers the upper Waikolu rim (1,100 m) area along the Hanalilolilo trail. The Puʻu Aliʻi Natural Area Reserve (NAR) is a summit plateau inhabited by wet forests, fern and shrub montane cliff communities, wet shrublands, and intermittent stream communities. It is an important part of the Molokaʻi watershed and contains forest bird habitat. In Puʻu Aliʻi NAR (1,160 m elevation) a pre-existing HFBS transect was utilized. Kūkaʻiwaʻa (30 m elevation) is a small peninsula east of Waikolu Valley, lying close to the offshore islets (Figure 6). The Kūkaʻiwaʻa transect runs along a 250 m fence transecting the peninsula east-west, then wraps around to the open coastal area.

Transects and stations were recorded with a Global Positioning System (GPS) Garmin GPSmap76 unit, utilizing the Universal Transverse Mercator, North American Datum 1983, Zone 4N.



Figure 5. View of lower Waikolu Valley and ʻŌkala Islet from Waikolu Overlook, Molokaʻi, 2005.



Figure 6. Aerial view of Kūkaʻiwaʻa Peninsula, Kalaupapa National Historical Park, Molokaʻi, 2005.

Small Mammal Inventory

The inventory was conducted in several phases in spring 2005 with each transect taking four days to complete. All 75 stations were set at 50 m intervals within each transect and were monitored for three consecutive nights each. The survey periods were: Puʻu Aliʻi NAR, 21–24 March; lower Waikolu Valley, 28–31 March; lower Waihānau Valley, 11–14 April; Kauhakō Crater, 19–22 April; Kūkaʻiwaʻa, 25–28 April; and upper Waihānau and upper Waikolu, 3–6 May.

We experimented with several methods of gathering presence/absence information for small mammals. Both removal and census methods were utilized at each survey station. One large and two small snap traps, a Tomahawk® live cage trap, a tracking tunnel, and a glue board were set at each station. Traps were set and checked approximately every 24 hours to remove captured individuals and to replace bait, if needed. Tracking tunnels and cage traps were baited with hot dogs, while snap traps and glue boards were baited with peanut butter. Logistics and cost prevented prebaiting at each site to allow for animals to investigate the introduction of foreign objects and food sources into their territories. Traps were anchored to avoid being moved by animals. Tomahawk® cage traps were strategically covered with vegetation, keeping the opening of the trap clear. This camouflaged the traps and created a tunnel effect, which likely made the traps more enticing to cats and mongooses. Animals captured in the Tomahawk® traps were photographed, marked with aerosol paint, and released unharmed since the purpose of the survey was to determine presence/absence and not to conduct predator control. If a rodent captured in a snap trap was still living when the trap was checked, it was euthanized with carbon dioxide gas. Captured individuals were identified to species and classified by sex *in situ*. Field staff were trained to sex animals utilizing available specimens. The field data collected included: date, time, observer, area, transect, station number, GPS waypoint, weather (cloud cover, estimated to the nearest 10%; wind, according to the Beaufort scale; and rain, based on a 0–4 scale), trap type, trap status (no catch, catch, tripped with bait, tripped without bait, bait replaced, bait stolen, trap missing, trap not checked, trap not set), species, age, and gender.

Trap shyness has been observed in Haleakalā National Park when attempting to trap feral cats (Bailey 2007). To increase detection of the feline population of KALA, tracking tunnels were utilized in the hope that they would prove to be more effective in recording presence. The effectiveness of the baited tunnels and tracking ink was tested over two nights in Waihānau Valley prior to the field study (14–16 March 2005). The water-resistant tracking tunnels are one meter in length, and 20 x 20 cm in height and width (Figure 7). A 20 x 20 cm area of tracking ink was placed in the center-bottom of the tunnel. The hot dog bait was placed on a small piece of leaf which in turn was placed in the center of the tracking ink. The animals' prints were captured upon exit on tracking paper (Figure 8). The proportion of stations with animal prints was determined for each species at each transect.



Figure 7. Small mammal tracking tunnel, Pu'u Ali'i Natural Area Reserve, Moloka'i, 2005.



Figure 8. Mongoose and feral cat tracks, lower Waihānau transect, Kalaupapa National Historical Park, 16 March 2005.

Two sizes of sticky or glue traps were purchased for use: the large Catchmaster® 45 x 28 cm traps, and the smaller Trapper® 11.5 x 23 cm traps. The glue boards were only used at stations where they could be safely sheltered from forest birds (Figure 9). The larger Catchmaster® glue traps were only used at Pu'u Ali'i NAR, as no other site provided adequate cover for the large boards. Extreme weather conditions (e.g. heat, sun, rain) compromise the effectiveness of the glue, often allowing a captured animal to free itself from the board, leaving only signs of its presence.



Figure 9. Small glue trap placement, Pu'u Ali'i Natural Area Reserve, Moloka'i, 22 March 2005.

Trapping results for rats and mice are reported by trap night. A trap night is one trap set per night. Mouse capture rates were calculated using the number of trap nights for both

rat and mouse snap traps because mice were sometimes caught in rat traps. Rat capture rates were calculated using only large rat traps and the large glue boards, which assumes it is not possible to capture a rat in the smaller mouse snap trap. We corrected our number of trap nights to account for sprung traps, which reflects sampling effort more accurately. We used the formula developed by Beauvais and Buskirk (1999) to assess trap nights:

$$\text{Corrected trap night} = (\text{traps} \times \text{nights}) - (\text{sprung traps} \times 0.5)$$

The corrected trap rate is reported as the number of individuals/100 CTN (corrected trap nights).

Sprung Tomahawk® traps (for cats and mongooses) were accounted for by calculating a sprung trap as half a trap night (Seymour et al. 2005).

RESULTS

This survey detected the presence of four mammalian species: black rat, house mouse, mongoose, and cat. The brief pilot study of the baited tracking tunnels showed that they were effective in determining the presence of some target species. We found that cats and mongooses did enter the tunnels and that the ink pads and tracking paper provided sufficient prints to identify species. The survey did not detect the presence of Norway and Polynesian rats. Although feral dogs (*Canis familiaris*) were not detected via any trapping or tracking method used in this survey, dogs were heard, and tracks noted all along the Pu'u Ali'i NAR transect.

Black rats were captured or recorded along all transects except upper Waikolu Valley. A total of 19 black rats were captured; 14 in large snap traps, four in small (mouse) snap traps, and one on a glue board (Table 2). Only in one instance did a glue trap capture a rat. All other 22 rat detections in glue traps showed signs of presence only (Table 6, Figure 10). Tracking tunnels showed the presence of rats on four occasions. The trap rate for rats/100 CTN was 3.48.

Table 2. Summary of black rat captures (large snap traps) and tracks at Kalaupapa National Historical Park, March–May 2005.

Area	Rat CTN ¹	# Rat Captures	Rat Capture Rate ²	Percent of Stations with Tracking Tunnel Rat Sign
Pu'u Ali'i NAR	67.5	3	4.4	0%
Upper Waikolu	62.5	0	0	0%
Upper Waihānau	62.5	2	3.2	0%
Lower Waihānau	63.5	1	1.5	0%
Lower Waikolu	64.5	3	4.72	9%
Kauhakō Crater	61.5	2	3.25	9%
Kūka'iwa'a	48	4	8.3	0%
Total	430	15	3.48	3%

¹Corrected trap nights; ²Number of rats per 100 corrected trap nights

House mice were found in Pu`u Ali`i NAR, upper Waikolu, upper Waihānau, and Kauhakō Crater. Ten mice were captured using both snap trap sizes (four mice) and the glue boards (six mice; Table 3). The glue traps also indicated four instances of mice sign (Table 6). There was no sign of mice in the tracking tunnels. The trap rate for house mice was 1.2.

Table 3. Summary of house mouse captures and tracks at Kalaupapa National Historical Park, March–May 2005.

Area	Mouse CTN ¹	# Mouse Captures	Mouse Capture Rate ²	Percent of Stations with Tracking Tunnel Mouse Sign
Pu`u Ali`i NAR	129.5	2	1.54	0%
Upper Waikolu	125	3	2.4	0%
Upper Waihānau	120.5	2	1.66	0%
Lower Waihānau	127	0	0	0%
Lower Waikolu	116	0	0	0%
Kauhakō Crater	118.5	3	2.53	0%
Kūka`iwa`a	93.5	0	0	0%
Total	830	10	1.2	0%

¹Corrected trap nights; ²Number of mice per 100 corrected trap nights

Mongoose were found at six of the seven transects and absent from lower Waikolu Valley. Forty-two mongooses were caught using the Tomahawk® traps (Table 4). Tracking tunnel results showed the presence of mongooses on 60 occasions. Two instances of mongoose sign (hair only) were documented by the glue traps (Table 6).

Table 4. Summary of mongoose captures and tracks at Kalaupapa National Historical Park, March–May 2005.

Area	Mongoose CTN ¹	# Mongoose Captures	Percent of Stations with Tracking Tunnel Mongoose Sign
Pu`u Ali`i NAR	33	2	9%
Upper Waikolu	32	8	45%
Upper Waihānau	26	1	9%
Lower Waihānau	33	3	82%
Lower Waikolu	32.5	0	0%
Kauhakō Crater	33	16	82%
Kūka`iwa`a	26	12	88%
Total	215.5	42	45%

¹Corrected trap nights

Feral cats were found in lower Waihānau Valley, lower Waikolu Valley and Pu`u Ali`i NAR. Two cats were trapped using the Tomahawk® traps (Table 5). Tracking tunnel results showed the presence of cats on three occasions. There was no cat sign recorded on the glue boards.

Table 5. Summary of cat captures and tracks at Kalaupapa National Historical Park, March–May 2005.

Area	Cat CTN ¹	# Cat Captures	Percent of Stations with Tracking Tunnel Cat Sign
Pu`u Ali`i NAR	33	1	0%
Upper Waikolu	32	0	0%
Upper Waihānau	26	0	0%
Lower Waihānau	33	0	27%
Lower Waikolu	32.5	1	0%
Kauhakō Crater	33	0	0%
Kūka`iwa`a	26	0	0%
Total	215.5	2	4%

¹Corrected trap nights

Glue boards recorded the presence of mice, rats, and mongooses. We observed 23 instances of rat sign or capture occurring at all transects except lower Waikolu Valley. Mouse sign or capture was documented at Pu`u Ali`i, upper Waikolu Valley, upper Waihānau Valley, and Kauhakō Crater, including one instance when two individuals were caught on the same board. We noted only two instances of mongoose sign on glue boards at upper Waikolu Valley and lower Waihānau Valley. No birds were captured or left sign, but there was one instance of a gecko being caught in a glue board. The glue boards neither captured nor recorded signs of any animals in lower Waikolu Valley.

Table 6. Summary of animal sign and captures¹ on glue boards in Kalaupapa National Historical Park, March–May 2005.

Type of Capture	Rat	Mouse	Mongoose	Avifauna
Sign Only	22	4	2	0
Animal Captured	1	6	0	0

¹227 total glue boards deployed



Figure 10. *Rattus* spp. hair and scat on small glue board, Kalaupapa National Historical Park, 2005.

Weather data collected for the census sessions are summarized in Table 7.

Table 7. Summary of weather conditions during census periods, March–May 2005.

Area	Average Cloud Cover (%)	Average Rainfall ¹	Average Wind Speed ²
Pu`u Ali`i NAR	68	0	2
Upper Waikolu	5	0	1
Upper Waihānau	16	0	1
Lower Waihānau	55	0	1
Lower Waikolu	94	1	1
Kauhakō Crater	14	0	3
Kūka`iwa`a	36	0	2

¹Rain Code: 0 = no rain, 1 = drizzle

²Wind Code: 1 = smoke drifts, 2 = leaves rustle, 3 = leaves and twigs move

DISCUSSION

We recorded the presence of non-native small mammals throughout the study area using a variety of censusing and removal methods. Black rats were the most ubiquitous species, followed by mongooses, house mice, and feral cats. However, mongooses had the most captures and the most evidence recorded of all four species. The presence of any of these species was not surprising; the absence of data for other common rat species was unexpected.

Black rats were found at every transect from low to high elevation areas. Snap traps, glue boards, and tracking tunnels recorded black rat sign or capture. Although Polynesian rats were not identified during this survey, they are known from all the main islands (Kramer

1971) and have been documented in high-elevation, native forests on Maui and Hawai'i (Stone et al. 1984, Sugihara 1997, Bailey 2007). When snap trapping was conducted on Mōkapu Islet just outside the KALA boundary in 2002, a Polynesian rat was collected (Wood and Legrande 2002). Since no other rodent surveys have been performed on Moloka'i, we compared our findings to other trapping programs conducted on Maui (Table 8). As Table 8 illustrates, the lack of Polynesian rats in KALA could be due to the relatively low elevation of the island. At KALA, even the highest elevation transect areas are below the lowest elevations of the studies that captured Polynesian rats on Maui. At similar elevations at Ka'āpahu on Maui, no Polynesian rats were caught. Another suggestion for the lack of Polynesian rat captures was the relatively low number of trap nights, both at KALA and at Ka'āpahu. More importantly, however, is that Polynesian rats are often not caught until black rat numbers have been reduced. It is possible that we did not remove sufficient black rats to have detected Polynesian rats at KALA.

Table 8. Comparison of captures per 100 trap nights for black rats and Polynesian rats among areas on Maui and Moloka'i.

Area	Black Rats	Polynesian Rats	Trap Nights	Elevation (m)
Wakamoi Nature Preserve & Hanawī NAR, Maui (Sugihara 1997)	11.25	6.37	2479	1,500–2,125
Kīpahulu Valley, Maui (Stone et al. 1984)	21.4	29.4	2100	1,240–2,050
Ka'āpahu, Haleakalā NP, Maui (Bailey 2007)	2.8	0	288	548–927
Kalaupapa NHP, Moloka'i (this study)	3.48	0	418.5 ¹	20–1180

¹Corrected trap nights

Given that we only caught 15 rats, the lack of Norway rats was not surprising. Similar data have resulted from work on Maui and the island of Hawai'i. In a four-year study of Hawai'i Island wet montane forests, Lindsey et al. (1999) captured 1,251 rats of which only 13 (one percent) were Norway rats. In a study of Waikamoi and Hanawī NARS on Maui, no Norway rats were among the 437 rat captures which occurred in forest habitat similar to that on Hawai'i Island (Table 8, Sugihara 1997).

Ecological impacts from non-native rodents vary with regards to bird species. Rodents can affect populations of native forest birds through predation, competition for resources, habitat degradation, and subsidization of predators on forest birds (Ebenhard 1988, Moors et al. 1992). The primary effect of small mammals such as rats on forest birds is predation of eggs, nestlings, fledglings, and sometimes adults (Atkinson 1977, Scott et al. 1986). Among the three rat species that inhabit Hawai'i, black rats are thought to be the most threatening agent in forest bird declines, mostly due to their arboreal nature (Atkinson 1977).

Black rats can have destructive effects on native plants. They have been known to strip the bark from koa trees (*Acacia koa*; Hess et al. 2004). We observed similar stripping of ohe makai (*Reynoldsia sandwicensis*) trees by rats at Kauhakō Crater in Kalaupapa. This

behavior inhibits the growth of koa; the effect on ohe makai is unknown. Rats and mice are known to prey on sandalwood seeds on West Maui (Hughes unpubl. data). Rodent populations present a significant threat to the reproduction of some plants on Moloka'i, and are a particular management concern for the numerous threatened and endangered species found there. We have seen evidence of predation by rats on lama (*Diospyros sandwicensis*), hō'awa, and hala seeds in coastal forests at Kūka'iwa'a and Ka'aloa and on loulu palm seeds at higher elevation forest at the back of Wai'ale'ia Valley (Hughes unpubl. data). The evidence consisted of partially eaten seeds found in small piles under native trees. Rats also cache large piles of hala seeds in the coastal forests of Kūka'iwa'a.

House mouse captures were infrequent and focused mainly in the higher elevation transects (above 730 m) except for the Kauhakō Crater (30–100 m), which is the survey site closest to human habitation. House mice are usually associated with drier grassland habitats (Tomich 1986). However, substantial mouse populations have been found in high elevation rain forests on Maui (Sugihara 1997), which supports our presence data at the higher elevation transects. This inventory did not record the presence of a considerable house mouse population. It does not seem that house mice pose much of a threat to native plant species in these numbers, though they do occur in primarily native and mixed habitats where damage to sensitive species is likely to occur.

Mongoose were by far the most often caught or recorded species in this survey. Even though mongooses are commonly found in higher elevations on Moloka'i, mongoose populations are highest in vegetation types below 610 m (2,000 ft) (Tomich 1986, Stone and Loope 1987). This is evident in our study as more captures were recorded at the lowest elevation areas, Kūka'iwa'a and Kauhakō Crater, than at the other study areas. Though this study found no evidence of mongooses at the lower Waikolu transect, we cannot assume that they are absent from this area.

Mongooses and cats are primary predators of endangered Nēnē and Hawaiian Petrel at Haleakalā National Historical Park (Simons 1983, Banko 1988, Natividad Hodges 1994, Baker and Baker 1996; Natividad Hodges and Nagata 2001). Laboratory tests show that mongooses are good tree climbers (Stone and Loope 1987) and may also depredate native forest bird species. The Nature Conservancy has documented the impacts of cats and mongooses on native seabird populations at Mo'omomi Preserve (Tachibana 2007). With the implementation of small mammal control programs, healthy shearwater nesting colonies were reestablished at the preserve. Wedge-tailed Shearwaters and Red-tailed Tropicbirds, both ground nesting species, were detected in KALA during the 2005 shoreline bird inventory (Kozar et al. in review) and are vulnerable to predation by mongooses and cats.

Cats were detected infrequently by live trap and tracking tunnels. They are difficult to capture and detect because of their stealthy nature. Data from Haleakalā National Park's trapping program from 1989 to 2004 found it took 936 to 19,635 trap nights to capture one cat (Bailey 2007) in forested subalpine habitat. The disparity in capture rate compared to this study (108 trap nights per cat) could be due to a larger cat population in KALA, differences in elevation and proximity to human settlement, or chance. More sampling is necessary to arrive at an accurate estimate of the feral cat population in KALA.

Feral cats are a culturally sensitive issue within the Kalaupapa Settlement, and any program to remove or reduce the feral cat population park-wide would require great

delicacy. Cats are regularly captured in the Kalaupapa settlement area for neutering and release. National Park Service staff and volunteer veterinarians captured and spayed or neutered 481 cats between January 1998 and March 2007 (NPS unpublished data). This informal program could account for trap shyness, especially close to the settlement. Cats have never been trapped in the backcountry.

Though this study was an inventory of small mammals, comparing the different censusing and trapping methods used provides worthwhile discussion for aiding future monitoring projects. The number of tracking tunnel signs for mongooses and cats was proportionally higher than the overall capture rate. On three occasions, cats visited the tracking tunnels, but only at the site located closest to houses and human settlement. On 24 occasions there were both tracking tunnel sign and a mongoose captured in a cage trap at the same station, suggesting the possibility that mongooses were more inclined to enter the tunnel before entering the trap.

Rats and mice had more captures or sign at the glue and snap traps baited with peanut butter than at the tracking tunnels baited with hot dog. For rats the number of tracking tunnel signs was low even on transects where the capture rate by snap or cage traps was high, and for mice there was no sign at the tracking tunnels. These discrepancies could be due to differences in the baits, the devices, the locations of the device, or some other factor. The peanut butter bait proved to be a poor choice in wet weather as it easily dissolved from the glue boards and the bait pedals on the snap traps. Isopods and ants were attracted to the peanut butter bait, and rebaiting was necessary in several instances. Logistics and cost prevented effective experimentation with different baits, which might have helped determine the best possible bait. This also prevented prebaiting at each site to allow animals to investigate the introduction of foreign objects and food sources into their territories. Instead, we experimented with several methods of gathering presence/absence information to help address this deficiency.

Glue traps were more effective as a censusing tool than as a removal method. Even if rats were not captured on the boards, the glue traps were especially successful in recording rat presence through hair or feces sign. Though most transects had rat snap trap captures as well, only glue boards recorded rat presence in the upper Waikolu Valley. Glue boards proved to be somewhat ineffectual in capturing rodents, with 28 instances of rodents freeing themselves from the traps compared to only seven captures. On one board we found a partially eaten mouse carcass, indicating that some of the “freed” captures may have been depredated while incapacitated. Leaves and twigs were often found stuck to the traps, creating areas where rodents could access the bait without getting trapped themselves. The weather also caused some malfunctions. During the survey session in lower Waikolu Valley, incessant precipitation caused the glue traps to be ineffective at catching individuals or capturing sign.

Dogs were detected throughout Pu`u Ali`i NAR. Pu`u Ali`i NAR as well as the adjacent Kamakou and Pelekunu Valley Nature Conservancy Preserves (The Nature Conservancy) are primarily managed using dog-assisted pig hunts. This creates a plausible scenario where stray hunting dogs could travel into and subsequently reside in Pu`u Ali`i NAR.

RECOMMENDATIONS

Populations of non-native small mammal species at KALA are a threat to the native flora and fauna. Therefore, it is important to conduct regular monitoring of priority species and select ecological areas. These data are necessary to secure authorization and registration for comprehensive methods to control non-native small mammal populations that affect both native bird and plant species.

Any presence of feral cats and mongooses is noteworthy as they are devastating predators of avian species. Urgent attention should be paid to the presence of feral cats and mongooses in Pu`u Ali`i NAR as it possesses the best possible habitat for the remaining native avifauna on Moloka`i. Additionally, despite the lack of evidence of feral cats in certain areas of this study, these species should not be presumed absent from any location within the park, especially when sensitive species are being actively protected or propagated.

Implementation of properly planned and executed cost-effective rodent control programs both along the coast and in high-elevation forests in KALA lands would likely benefit reproduction efforts of rare native plant populations like hō`awa and loulou palm, reintroduced forest bird species, and vulnerable ground-nesting seabirds such as Wedge-tailed Shearwaters, Red-tailed Tropicbirds, and White-tailed Tropicbirds. In particular, the aerial broadcasting of rodenticide in selected target areas is an important management strategy to consider for this region. The distribution of the rodenticide can be controlled fairly accurately and requires few field days. Additionally, considering the steep terrain of most of the park, this method would facilitate a fairly even distribution in the focal area.

Future censusing of small mammals could benefit from the trapping and tracking methods we used. The tracking tunnels provided a good deal of presence data, especially for mongooses, cats, and rats. Adding a mouse-specific bait to the carnivore bait may result in mouse sign at the tracking tunnels as well. Since a tracking station may be visited by the same animal repeatedly, estimating population size from this method is not possible; however, it is suitable for determining presence/absence. Glue boards are also helpful in gathering presence data for small mammals, especially the rodents. For removal techniques, the snap traps and live traps were more successful, though the choice of baits should be given some thought and prebaiting is also recommended. The likelihood of capturing cats may be increased by using more pungent bait, such as rotting fish, to lure more cats to the trapping area. Replacing or cleaning the cage traps and tracking tunnels after a capture and by increasing the number of consecutive trap nights may also increase cat capture/sign. A better choice of bait, such as coconut, is recommended for future rodent censusing in this region, as it would not be adversely affected by weather conditions and can be easily transported by field personnel. Coconut could be glued to snap traps to reduce instances of stolen or lost bait.

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